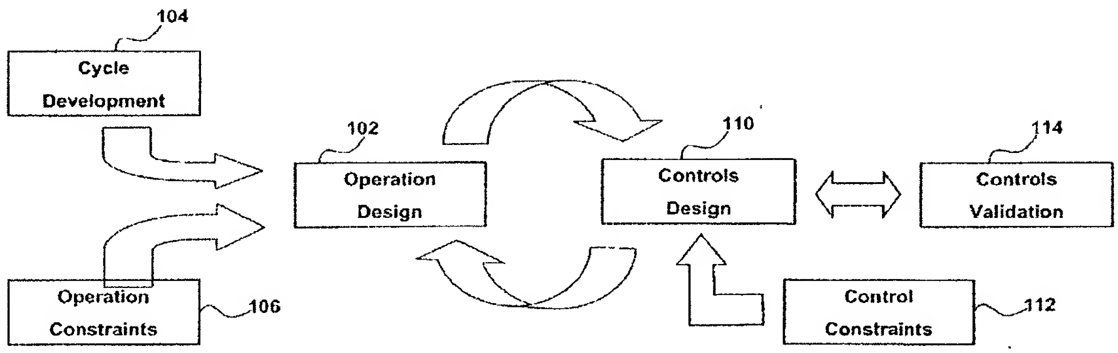
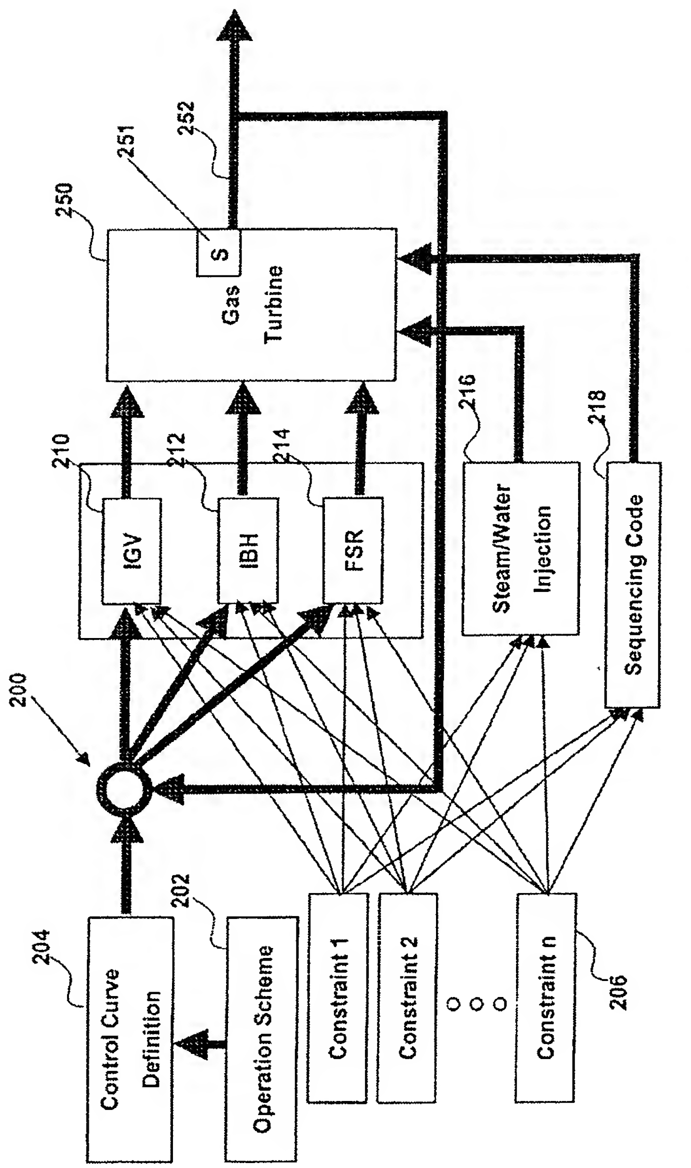

104
Cycle
Development
102
Operation
Design
110
Controls
Design
114
Controls
Validation
Operation
Constraints
106
Control
Constraints
112

FIG. 1



250
251
252
Gas Turbine
S
210
212
214
IGV
IBH
FSR
216
Steam/Water Injection
218
Sequencing Code
200
204
Control Curve Definition
202
Operation Scheme
Constraint 1
Constraint 2
Constraint n
206

FIG. 2

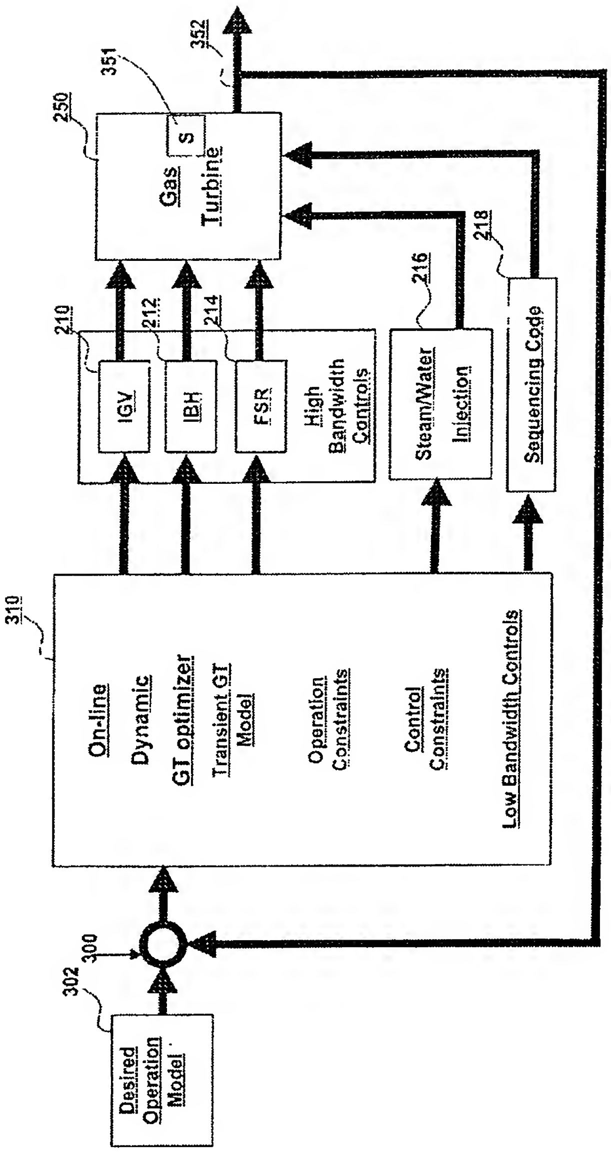

250
351
352
Gas
Turbine
S
210
212
214
IGV
IBH
FSR
High
Bandwidth
Controls
216
Steam/Water
Injection
218
Sequencing Code
310
On-line
Dynamic
GT optimizer
Transient GT
Model
Operation
Constraints
Control
Constraints
Low Bandwidth Controls
302
300
Desired
Operation
Model

FIG. 3

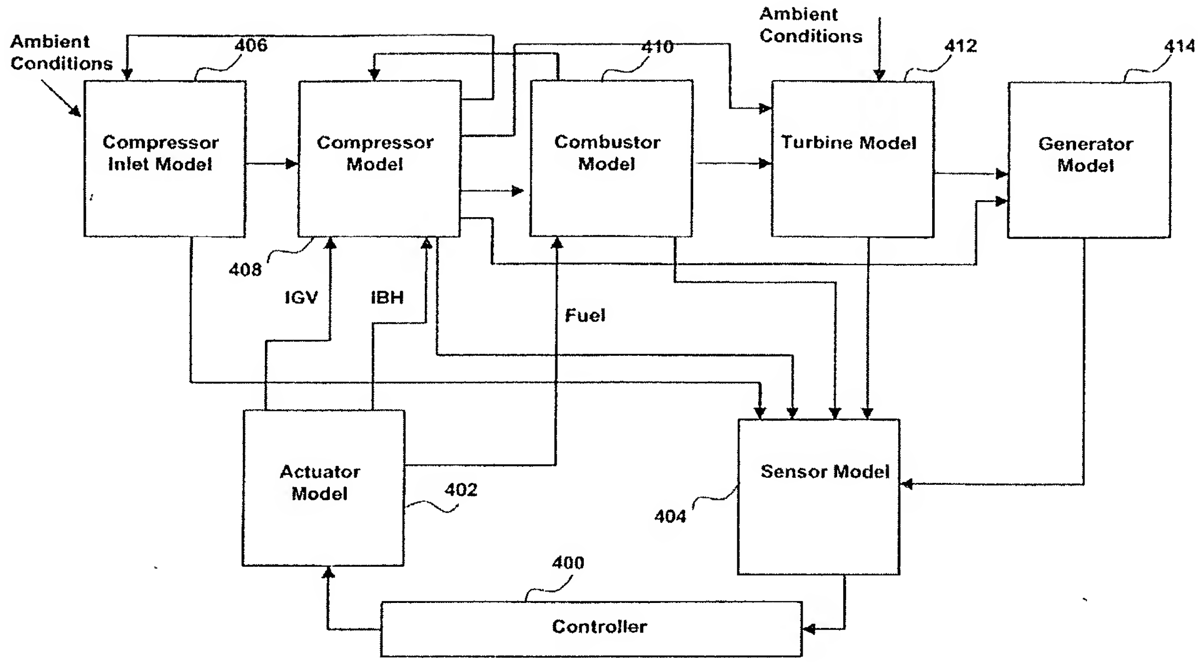

Ambient Conditions
406
Compressor Inlet Model
Compressor Model
408
410
Combustor Model
Ambient Conditions
412
Turbine Model
414
Generator Model
IGV
IBH
Fuel
Actuator Model
402
Sensor Model
404
400
Controller

FIG. 4

Compressor Inlet Model

$$\dot{m}_{comp} c_p T_{comp,in} = \dot{m}_{bleed} c_p T_{bleed} + \left(\dot{m}_{comp} - \dot{m}_{bleed}\right) c_p T_{amb}$$

$$P_{comp,in} = P_{amb} - \Delta P_{inlet}$$

$$\Delta P_{inlet} = f\left(\dot{m}_{comp}\right)$$

$$Specific\ Humidity = \frac{0.622 * (Relative\ Humidity)}{\left(\frac{P_{amb}}{P_{dry}} - Relative\ Humidity\right)}$$

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Compressor Model

$$\dot{m}_{comp,corrected} = f\left(X_c, N_c\right)$$

$$\eta_{comp} = f\left(X_c, TNH_{cor}, SH\right)$$

$$\dot{m}_{comp} = \dot{m}_{comp,corrected} \frac{\sqrt{\frac{T_{comp,in}}{T_{ISO}}}}{\frac{P_{comp,in}}{P_{iso}}} + f(SH)$$

$$T_{comp,exit} = \frac{T_{comp,in}}{\eta_{comp}}\left[\left(X_c\right)^{\frac{\gamma-1}{\gamma}} - 1\right] + T_{comp,in}$$

$$\dot{m}_{9th,stage} = f\left(X_c, N_c, IGV\right)$$

$$\dot{m}_{13th,stage} = f\left(X_c, N_c, IGV\right)$$

$$\dot{m}_{17th,stage} = f\left(X_c, N_c, IGV\right)$$

$$\dot{m}_{18th,stage} = f\left(X_c, N_c, IGV\right)$$

504

FIG. 5A

Compressor Model Continued

$$\dot{m}_{nonchargeable} = \frac{C_d A P_{comp,exit}}{\sqrt{R T_{comp,exit}}} \left(\gamma^{1/2}\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}\right)$$

$$\dot{m}_{dicharge\ volume} = \dot{m}_{comp} - \dot{m}_{9th,stg} - \dot{m}_{13th,stg} - \dot{m}_{17th,stg} - \dot{m}_{18th,stg} - \dot{m}_{nonchargeable}$$

$$\dot{P}_{comp,exit} = \frac{\dot{m}_{dicharge\ volume} R T_{comp,exit}}{V_{discharge}}$$

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Since bleed flows are from the compressor to the turbine via some piping, a small lag is introduced in the flows to account for this:

$$\frac{d\dot{m}_{ith,stg\ bleed\ to\ turbine}}{dt} = \frac{\dot{m}_{ith,stg\ bleed\ from\ compressor} - \dot{m}_{ith\ stg\ bleed\ to\ turbine}}{\tau_{comp}}$$

Compressor Heat Soak Model

$$\frac{dT_{metal}}{dt} = \frac{Q}{m_{metal} c_{p,metal}}$$

$$Q = h\left(T_{comp,avg} \quad T_{metal}\right)$$

$$T_{comp,avg} = \frac{T_{comp,exit} + T_{9th,stg}}{2}$$

506

FIG. 5B

Compressor Model Continued

Compressor HP Calculation

$$CompressorHP = \dot{m}_{comp} c_p T_{comp,in} - \dot{m}_{9thstg} c_p T_{9thstg} - \dot{m}_{13thstg} c_p T_{13thstg} - \dot{m}_{17thstg} c_p T_{17thstg} - \dot{m}_{18thstg} c_p T_{18thstg} - (\dot{m}_{comp} - \dot{m}_{9thstg} - \dot{m}_{13thstg} - \dot{m}_{17thstg} - \dot{m}_{18thstg}) c_p T_{comp,exit}$$

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Combustor Model

$$T_{flame} = f\left(\dot{m}_{fuel}, \dot{m}_{comb}, T_{air,combin}, T_{fuel}, SH, P_{comp,exit}\right)$$

$$\Delta P_{comb} = f\left(P_{comp,exit}, T_{comp,exit}, T_{flame}, SH\right)$$

Combustor dynamics modeled with a lag for flame temperature and turbine inlet pressure:

$$\frac{dT_{flame,out}}{dt} = \frac{T_{flame,in} - T_{flame,out}}{\tau_{comb}}$$

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$$\frac{dP_{turbine,in}}{dt} = \frac{(P_{comp,exit} - \Delta P_{comb}) - P_{turbine,in}}{\tau_{comb}}$$

FIG. 5C

$\dot{m}_{comp}$	Total mass flow from compressor
$T_{comp,in}$	Temperature of air entering compressor
$\dot{m}_{bleed}$	Mass flow of inlet bleed air
T_{amb}	Ambient temperature
$P_{comp\,in}$	Inlet pressure to compressor
ΔP_{inlet}	Inlet pressure drop
P_{amb}	Ambient pressure
P_{dry}	Dry vapor pressure
$\dot{m}_{comp,corrected}$	Corrected mass flow from compressor
X_c	Pressure ratio across compressor
N_c	Corrected speed
TNH_{cor}	Corrected speed
η_{comp}	Compressor efficiency
c_p	Specific heat at constant pressure
$T_{comp,exd}$	Compressor discharge temperature
γ	Ratio of specific heats
IGV	Inlet guide vane angle
P_{ISO}	Pressure at ISO conditions
T_{ISO}	Temperature at ISO conditions
$\dot{m}_{nonchargeable}$	Mass flow from compressor directly to turbine inlet
R	Gas constant
C_dA	Effective area
$\dot{m}_{dischargevolume}$	Mass flow in the compressor discharge plenum
$V_{discharge}$	Volume of compressor discharge plenum
τ_{comp}	Compressor time constant
Q	Heat flux
h	Heat transfer coefficient
m_{metal}	Compressor mass
$c_{p,metal}$	Heat capacity of compressor
CompressorHP	Horsepower absorbed by compressor
T_{flame}	Flame temperature
ΔP_{comb}	Combustor pressure drop
τ_{comb}	Combustor time constant
$P_{turbine,in}$	Turbine inlet pressure

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Fig. 6

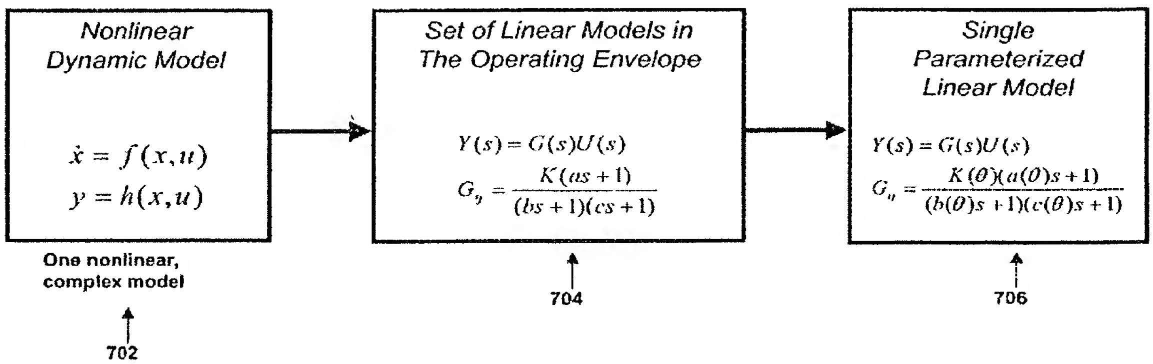
Nonlinear Dynamic Model
$\dot{x} = f(x,u)$
$y = h(x,u)$
One nonlinear, complex model
702
Set of Linear Models in The Operating Envelope
$Y(s) = G(s)U(s)$
$G_{ij} = \frac{K(as+1)}{(bs+1)(cs+1)}$
704
Single Parameterized Linear Model
$Y(s) = G(s)U(s)$
$G_{ij} = \frac{K(\theta)(a(\theta)s+1)}{(b(\theta)s+1)(c(\theta)s+1)}$
706

FIG. 7

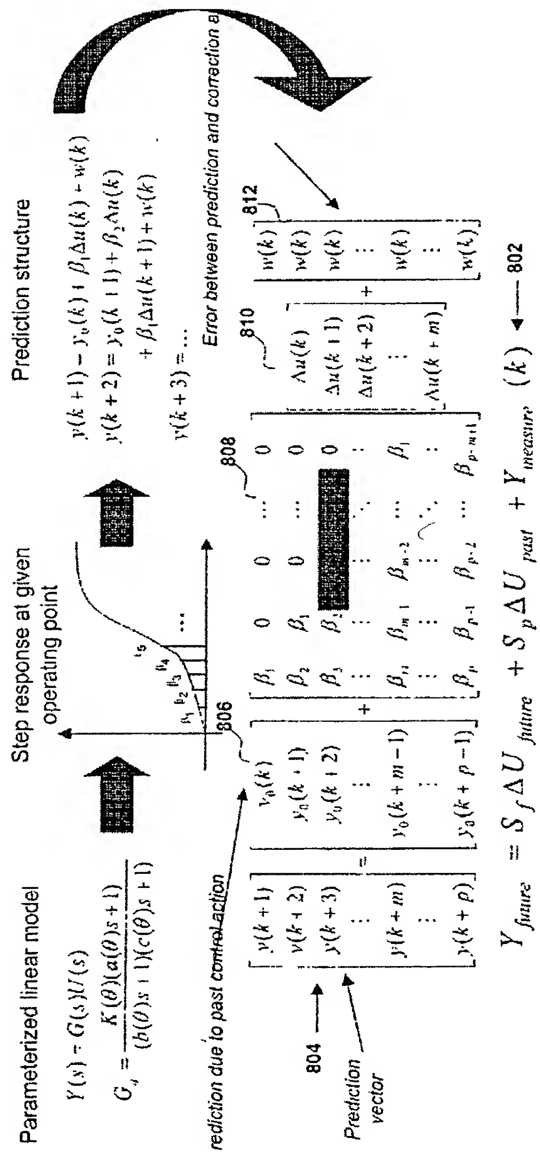
Parameterized linear model
$Y(s) = G(s)U(s)$
$G_s = \frac{K(\theta)(a(\theta)s+1)}{(b(\theta)s+1)(c(\theta)s+1)}$
Step response at given operating point
Prediction structure
$y(k+1) = y_0(k) + \beta_1\Delta u(k) + w(k)$
$y(k+2) = y_0(k+1) + \beta_2\Delta u(k) + \beta_1\Delta u(k+1) + w(k)$
$y(k+3) = \ldots$
Error between prediction and correction
rediction due to past control action
Prediction vector
804
806
808
810
812
802
$Y_{future} = S_f \Delta U_{future} + S_p \Delta U_{past} + Y_{measure}(k)$

FIG. 8

$$\text{minimize} \quad [Y_{future} - Y_{setpoint}]^2 + \Delta U^2$$

with respect to

$$Y_{lb} \leq Y_{future} \leq Y_{ub}$$

$$\Delta U_{lb} \leq \Delta U_{future} \leq \Delta U_{ub}$$

$$g(Y_{future}) \leq \text{Constraint} \quad s$$

Energy minimization (min. Heat Rate)

Nonlinear Constraints (LBO, SM, NOx)

904

Quadratic Programming Problem

$$\textit{minimize} \quad \Delta U^T Q \Delta U + f' \Delta U$$

with respect to

$$C \Delta U_{future} \leq C_{ub}$$

902

FIG. 9